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Conclusion and Future Work

This chapter focuses on conclusion and future prospects of this thesis work. Throughout the research work, our main focus was on hydrogen sensors. As hydrogen became most desirable fuel technology and is highly used in commercial applications and fast growing industrial applications. ZnO nanorods based hydrogen sensors were fabricated which showed lower limit of detection with high sensor response, fast response and recovery time at low operating temperature which became of utmost priority due to highly flammable nature of hydrogen gas even at low concentration,.

Thus based on the work present in this thesis, the following key points can be drawn:

Firstly, nano-crystalline ZnO thin films and ZnO NRs have been optimized using sputtering technique. These deposited thin films are of high crystalline nature and the in- plane stress can be optimized by varying deposition parameters. By further varying deposition parameters, well aligned ZnO nanrods can be grown on various substrate like Si, Ge, ITO coated glass, Pt/Si and Polyimide substrates. These deposited nanorods shows high crystallinity, uniform deposition throughout the substrate with larger aspect ratio and shows high optical properties with less number of intrinsic defects.

Secondly, to understand the significant role of heterojunctions (HJs) in semiconductor device performances, ZnO NRs/ Si heterojunction have been fabricated. Temperature depended I-V characteristic have been studied that explains its current conduction mechanism and presence of barrier inhomgeneities at heterojunction. Because of formation of Schottky barrier at HJ, current conduction mechanism has been supported by TE model and Schottky barrier and ideality factor varies with operating temperature. TE model with double Gaussian distributions of barrier height is used for calculating Richardson constants. Thus, calculated modified Richardson constant of ~ 123 $Acm^{-2}K^{-2}$ was obtained which is close to ideal Richardson constant for n-Si.

Thirdly, ohmic contacted ZnO NRs based hydrogen sensor have been fabricated for low operating temperature applications. These deposited nanorods shows less number of intrinsic defects which are confirmed by PL spectra and VSM characterization. ZnO NRs/ n-Si/ ZnO NRs double Schottky junction enhances sensor's response ~10.05% with fast response time of ~21.6 sec and recovery time of ~27 sec even at low operating temperature of 70 ºC for pure hydrogen.

Fourthly, Schottky contacted ZnO NRs based hydrogen sensors have been fabricated to further enhance sensor's response and reduce lower limit of detection. Initially, Au/ZnO NRs based hydrogen sensor enhances sensors response from 11% to 76% with fast response time (9-16 sec) with operating temperature varying from 50 ºC to 150 ºC in presence of 1% hydrogen concentration. Schottky contact such as Au and Pd also plays an important role in sensors performance. So, for further enhancement in sensor's response, Pd/ZnO NRs based sensors have been fabricated. It shows high sensor response ranging from 13.86 % to 91.26 % for 5ppm to 1% hydrogen concentration variation with operating temperature ranging from 50 ºC to 175 ºC. Even at low operating temperature of 50 ºC, sensors give 13.86 % as sensor response for 5ppm hydrogen concentration. Thus, the sensor shows high selectivity towards hydrogen (32% sensors response) with low limit of detection of 5 ppm in comparison to 100 ppm CH_4 (10%), 500 ppm H_2S (12.8%) and 1% CO_2 gases at 175 ºC operating temperature.

Fifthly, Post deposition techniques such as gamma irradiation and swift heavy ion (SHI) irradiation have been used for modification of material properties that modifies sensor's response to a large extent. Initially, Au/ZnO NRs based sensor have been irradiated with various gamma radiation fluences which modifies surface morphology and crystallography of ZnO NRs. At low gamma doses of 1kGy, sensor's response increases up to ~14% for 1% hydrogen concentration. Furthermore, nanocrystalline ZnO thin film based hydrogen sensor response also increases from 66.8% to 89.84% for 5% hydrogen at 175 ºC operating temperature when sensor is irradiated with 120 MeV Au ions at moderate fluences.

Therefore, ZnO NRs based hydrogen sensor with high sensor response, low limit of detection and fast response recovery time can be achieved at low operating temperature. For the possibility of future extension of this thesis work, listed proposed work is given below:

- To make further energy efficient hydrogen sensor, micro-heater with ZnO NRs based hydrogen sensor can be fabricated.

- For efficient hydrogen sensor, selectivity is key concern which has to be explored.

- By doping ZnO NRs with transition metal (Ni, Cu, Cr etc.), sensors response as well as sensors performance can be modified.

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